Measuring the Potential of Renewable Energy

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Overview of the Presentation

- Introduction
- Approach
- Modeling Framework
- Results
- Conclusions
- Limits and Next Steps
Introduction

- Over the last decade, energy policy has been steadily growing focus on “sustainability”.
- Federal agencies are constantly being asked to design and demonstrate performance results for their R&D programs and policy.
- There is a need for the measure of the performance of R&D investment in renewable technologies for electricity generation.
- Such information may be useful for program managers and other decision makers in guiding the allocation of limited resources.
Our Approach is to

- Develop an index-based measure to estimate consumer welfare gain as renewable energy technologies continue to be improved and gradually adopted compared with a counterfactual scenario that allows for continual improvement of conventional technology (defender technology).
- Adoption rate: we assume that the generation shares of renewable technologies, which replace the incremental generation of conventional technology, increase monotonically with time according to the Weibull process.
- Externality: internalize the externality associate with electricity
- Uncertainty: costs of electricity generation over 20 years
Illustration of Net Surplus Change Due to Innovation
Illustration of Net Surplus Change with External Costs
Derivation of Estimating Consumer Surplus

- We construct a Tornqvist cost index to measure the surplus changes due to innovations.
- The index is the geometric mean of a Laspeyres index – measuring consumer willingness to accept compensation to give up the gains from investment-in-renewables; and a Passche index, measuring their willingness to pay to receive gains from investment-in-renewables.
Laspeyres index:
The minimum cost of achieving utility $u^{dt}$, relative to the cost of $u^{dt}$ given the investment-in-renewables.

$$C^{*dt} = \frac{E^* (u^{dt}, P^{dt}, W^{dt})}{E^* (u^{dt}, P^{I}, W^{RE})}$$ (1)

Passche index:
The cost of achieving optimal utility $u^{I}$ under the investment-in-renewables scenario with baseline price $W^{dt}$ relative to the cost with post-innovation prices $W^{RE}$.

$$C^{*I} = \frac{E^* (u^{I}, P^{dt}, W^{dt})}{E^* (u^{I}, P^{I}, W^{RE})}$$ (2)
The **quality-adjusted cost** of renewables faced by post-adoption consumer is a combination of use of renewables and conventional technology:

\[ W^{RE} = \rho W^I + (1-\rho) W^{dt} \]  

(3)

We assume that the consumer expenditure function can be represented by a translog functional form. Thus, the log of Tornqvist index reduces to

\[ \frac{1}{2} \ln (C^{*dt} \times C^{*I}) = \frac{1}{2} (s^{dt}+s^I) \ln (W^{dt}/ W^{RE}) \]  

(Bresnahan, AER 1986)

The terms \( s^{dt} \) and \( s^I \) give, respectively, electricity expenditures as a share of personal consumption expenditure (PCE) under the baseline and investment-in-renewables scenarios.
Using the Index to Estimate the Present Value of Consumer Surplus

- The monetary value to consumers of the innovation is just the product of the predicted PCE times the exponent of the Tornqvist cost index minus one.
Model Framework

Private Generation Costs
{PV, ST, GEO, BIO, Wind, CCGT, A-CCGT}
(DOE/EIA (2000), DOE/EPRI (1997), authors’ adjustments)

Externality Costs
• Carbon (CCGT) (Krupnick et al. (1996))
• Thermal H₂O (CCGT, Biomass, ST) (Authors’ estimates)

“Market Conditions”
• Adoption rates
• Electricity prices (DOE/EIA (2000))
• Generation quantity (DOE/EIA 2000))

Private and Social Generation Costs

Cost Indices

Aggregate Consumer Surplus
• Discount rate

Private Consumption Expenditures
(DOC (2001), authors’ forecasts)
Diversity of Renewable Energy Resources in the United States

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Electricity Market Module Supply Regions
Defined by the North American Electric Reliability Council
Approach

• Some Application Features
  – Electricity generation technologies:
    • Renewable (PV, solar thermal, biomass, wind, geothermal)
    • Fossil (Conventional and advanced combined cycle gas turbine, CCGT)
  – Two geographic regions (CNV, MAPP):
    We chose these regions to highlight regional differences in resource endowments for power generation.
Weibull Adoption Rate Curves

\[ F(t) = 1 - \exp(-\lambda t^\gamma) \]
External Effects

- Carbon
- Water
- Land use
- Avian and other ecological resources
Uncertainty

- Sources of uncertainty
- Parameterization of input variables
- Random draws – Monte Carlo
- Sensitivity tests for what matters most
Results I:
Discounted incremental net benefits from 2000 to 2020 for Wind 6 from scenario 1 for CNV
Results II:
The present value of benefits from 2000 to 2020 for Wind Class 6 from scenario 1 for CNV
# Results III

**Scenario 1:**  
*Weibull: .1, 3.5*  
*Externalities: Carbon Water*  
*Base: EIA CCGT Growth*  
*Discounted Present Value, 2000-2020, $1999 billions*

<table>
<thead>
<tr>
<th>Innovating Technology</th>
<th>Conventional CCGT (5%, Median, 95%)</th>
<th>Advanced CCGT (5%, Median, 95%)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>CNV</td>
<td></td>
</tr>
<tr>
<td>Photovoltaics</td>
<td>(-13.6, -10.8, -8.04)</td>
<td>(-13.7, -10.9, -8.08)</td>
</tr>
<tr>
<td>Solar Thermal</td>
<td>(-7.02, -5.38, -3.86)</td>
<td>(-7.17, -5.57, -3.96)</td>
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<tr>
<td>Geothermal</td>
<td>(2.62, 3.47, 4.45)</td>
<td>(2.51, 3.31, 4.26)</td>
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<tr>
<td>Wind Class 4</td>
<td>(2.10, 2.90, 3.77)</td>
<td>(2.00, 2.73, 3.61)</td>
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<tr>
<td>Wind Class 6</td>
<td>(3.50, 4.60, 5.80)</td>
<td>(3.35, 4.44, 5.59)</td>
</tr>
<tr>
<td>Biomass</td>
<td>(-5.37, -3.99, -2.74)</td>
<td>(-5.46, -4.17, -2.88)</td>
</tr>
<tr>
<td></td>
<td>MAPP</td>
<td></td>
</tr>
<tr>
<td>Photovoltaics</td>
<td>(-6.40, -4.62, -2.92)</td>
<td>(-6.51, -4.70, -2.97)</td>
</tr>
<tr>
<td>Solar Thermal</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Geothermal</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Wind Class 4</td>
<td>(0.79, 1.18, 1.65)</td>
<td>(0.74, 1.09, 1.56)</td>
</tr>
<tr>
<td>Wind Class 6</td>
<td>(1.14, 1.75, 2.41)</td>
<td>(1.13, 1.67, 2.31)</td>
</tr>
<tr>
<td>Biomass</td>
<td>(-1.61, -1.10, -0.64)</td>
<td>(-1.75, -1.17, -0.69)</td>
</tr>
</tbody>
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# Results IV

**Largest Surplus Gains Under An Exogenously Specified “Portfolio”**

Discounted Present Value 2000-2020, $ 1999 Billions

**Base: EIA CCGT Growth**

<table>
<thead>
<tr>
<th></th>
<th>CNV (5%, Median, 95%)</th>
<th>MAPP (5%, Median, 95%)</th>
<th>Assumptions:</th>
</tr>
</thead>
<tbody>
<tr>
<td>EQWTRP</td>
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<tr>
<td>C-CCGT</td>
<td>(-1.54, -1.11, -0.72)</td>
<td>(-1.07, -0.72, -0.42)</td>
<td>Weibull: .05, 3.5</td>
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<tr>
<td>A-CCGT</td>
<td>(-1.63, -1.20, -0.77)</td>
<td>(-1.13, -0.79, -0.78)</td>
<td>External Effects: Carbon, Water</td>
</tr>
<tr>
<td>VARWTRP</td>
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<tr>
<td>C-CCGT</td>
<td>(0.41, 0.84, 1.28)</td>
<td>(0.59, 0.92, 1.25)</td>
<td>Weibull: .1, 3.5</td>
</tr>
<tr>
<td>A-CCGT</td>
<td>(0.22, 0.68, 1.11)</td>
<td>(0.56, 0.83, 1.17)</td>
<td>External Effects: Carbon, Water</td>
</tr>
</tbody>
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Conclusions

• Using a cost index that is well grounded in demand theory, we develop a stochastic simulation model
  – to estimate value of cost index
  – to estimate net present values of consumer surplus
  – to identify and study effects of uncertainty
  – to provide DoE with a policy management/resource allocation tool

• The model also allows
  – regional differences
  – adoption push
  – externality internalization
Limits and Next Steps

- One by one comparison
  - OK for R&D investment planning?

- Limited info on externalities
  - Rigorous attention to a wider array of externalities constitutes a major area for further research in understanding the comparative economics of renewable and conventional energy

- Additional scenarios, such as RPS?
Thanks you